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FOREWORD

The 17th Canadian Hydrology Symposium was held on May 9-11, 1988, at the Banff Centre, Banff, Alberta, under the auspices of the National Research Council of Canada's Associate Committee on Hydrology. This symposium brought together most of those who have been involved in research in or management of Canada's Research Basin Program. These proceedings contain two distinct types of papers:

- Reviews of particular research basins.
- Reports on research conducted in conjunction with a research basin.

The review papers were solicited by the program committee in order to provide a written record of the many research basins that exist across Canada. Research papers were voluntary. The papers contained herein have been retyped, with minimal editing and printed essentially as they were received, without referee review. A special word of thanks goes to Pierre Bernier for his translation of most of the abstracts to French.

I wish to thank the following people whose efforts made this symposium a reality. The program committee consisted of Dave Daugharty, Eugene Hetherington, Bob Swanson and Trevor Dickinson (Chairman). Local arrangements were handled by Ron Deeprose and Judy Lindsay.

AVANT-PROPOS

Le 17[ième] Symposium Canadien d'Hydrologie s'est déroulé au "Banff Centre", Banff, Alberta, du 9 au 11 mai 1988, sous les auspices du Comité Associé sur l'Hydrologie du Conseil National de Recherches du Canada. Ce symposium rassemblait la plupart des personnes qui ont été impliquées dans les aspects de recherche ou de gestion du Programme Canadien de Bassins de Recherches. Ce compte-rendu contient deux types de communications:

- Les synthèses sur des bassins de recherches particuliers.
- Les présentations de résultats de recherches menées sur un bassin.

Les synthèses étaient toutes des communications invitées. Le comité du programme tenait ainsi à obtenir un compte-rendu écrit sur les activités de tous les bassins de recherches au Canada. Les communications de recherche étaient volontaires. Les communications contenues dans ce compte-rendu ont été mises en page avec peu d'édition, et ont été imprimées essentiellement comme reçues des auteurs, sans comité de lecture. La traduction au français des résumés et autres textes a été réalisée par Pierre Y. Bernier.

Je désire remercier les personnes qui ont rendu cette rencontre possible. Le comité du programme était composé de Dave Daugharty, Eugene Hetherington, Bob Swanson et Trevor Dickinson (Président). Les arrangements locaux ont été organisés par Ron Deeprose et Judy Lindsay.

R.H. Swanson
General Chairman/Président Général
Canadian Hydrology Symposium - 88/Symposium Canadien d'Hydrologie -88

PRÉFACE

En 1964, le Comité Associé sur l'Hydrologie du Conseil National de Recherches tenait un symposium sur les "bassins de recherches"[1], similaire à celui-ci, à Guelph en Ontario. Dans son allocution d'ouverture, le Dr. R.H. Clark demandait:

> La valeur de cette approche [des bassins de recherches] est-elle suffisante pour justifier l'investissement de tels montants et de tels efforts sur de si longues périodes?

Un des principaux objectifs de cette rencontre-ci sur la révision des bassins de recherches est justement de répondre à cette question.

La majorité d'entre nous qui oeuvrons en hydrologie voulons des données. Est-ce que la quantité, qualité et la pertinence des données récoltées par le programme canadien de bassins de recherches a su justifier son existence? En général, oui, malgré que le besoin en données hydrométéorologiques nouvelles sera toujours là. Mais ce besoin est sans doute moins impérieux qu'en 1964 car le programme a fourni une abondance de données sur l'hydrologie de régions, et sur les différences hydrologiques entre régions.

La majorité d'entre nous désirent une meilleure qualification du personnel. Le programme canadien de bassins de recherches a-t'il mis à la disposition des organismes responsables des ressources en eau du personnel compétent? Ces personnes utilisent-t'elles leur expertise ou ont-t'elles été détournées vers des postes administratifs? Nous pouvons sans doute dire que le besoin en hydrologistes qualifiés sera toujours là. Un des résultats du programme canadien de bassins de recherches est le grand nombre de personnes qui se disent hydrologistes.

Est-ce que nous, les hydrologistes, nous appliquons dans notre travail ce que nous avons appris grâce au programme canadien de bassins de recherches? L'étendue du Canada, la diversité de sa topographie, de son climat et de son hydrographie nous masquent souvent le fait que les principes hydrologiques de base sont les mêmes partout. Il pleut ou il neige; la transpiration des plantes transfère de l'eau du sol à l'atmosphère; l'évaporation s'effectue à partir de l'eau à la surface de la végétation, du sol, des lacs et des rivières; les eaux de surface et souterraines se drainent dans des cours d'eau coulant vers les océans d'où provient l'eau pour la pluie et la neige. Ces éléments sont connus, et la plupart d'entre nous qui avons été formés en hydrologie possédons suffisamment de connaissances ou d'expérience pour estimer l'effet d'un de ces processus sur le régime et la quantité d'écoulement d'un bassin. Appliquons nous cette compréhension du système à la gestion des ressources hydriques ou au choix d'activités de recherche?

La question du Dr. Clark restera sans doute toujours sans réponse. La valeur du programme canadien de bassins de recherches vient de ce que nous en avons appris, du degré d'application de ces connaissances à la gestion des ressources hydriques, et de ce que nous pouvons éviter de répéter suite au programme. Nous devons nous servir de l'expérience et des données acquises à la fois comme base et comme point de départ pour les activités en hydrologie.

R.H Swanson
Président Général
Symposium Canadien d'Hydrologie - 88

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[1] Compte-rendu du Symposium d'Hydrologie No.4, tenu au Ontario Agricultural College, Université de Guelph, les 27 et 28 mai 1964.

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CANADIAN HYDROLOGY SYMPOSIUM (CHS:88)
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SYMPOSIUM CANADIEN D'HYDROLOGIE (SCH:88)
COMITÉ ASSOCIÉ D'HYDROLOGIE
CONSEIL NATIONAL DE RECHERCHES CANADA
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BANFF, ALBERTA

Research on Canadian glaciers within the IHD/IHP

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ABSTRACT The paper describes and evaluates glacier research projects included in the Canadian IHD/IHP program. The program of combined heat. Ice and water balance projects conducted within representative basins in the Western Cordillera and the Arctic is described.

The criteria employed for choice of basin and the manner in which research was undertaken are described. An evaluation of the success of the program is made in terms of the development of both Canadian and international understanding of glacier hydrology.

Some projects were specifically designed to accomplish short-term research objectives while others were designed with long-term monitoring and data collection as the basis for understanding the glacier systems. Well-equipped, semi-permanent research facilities were built at several of the long-term monitoring sites; some of these sites have been used also as bases from which to conduct short-term and site-specific research projects.

There has been an evolution in the objectives of some of the long-term projects; especially significant is the evolution from studying small basins very intensively to the incorporation of the knowledge gained into regional scale hydrological models. In future there is likely to be greater emphasis on models which integrate all aspects of high mountain hydrology and models which explore the climate-glacier-hydrology linkages.

RÉSUMÉ Ce rapport renferme la description et l'évaluation des projets de recherche sur les glaciers dans le cadre du programme DHI/PHI canadien; on y décrit également le programme des projets de bilan combinés de chaleur, de glace et d'eau qui sont appliqués dans des bassins représentatifs dans la cordillère de l'Ouest et dans l'Arctique.

Les critères servant au choix du bassin et le mode d'exécution des recherches sont décrits. On présente une évaluation des succès du programme sur le plan de l'accroissement de la compréhension, au Canada et dans la collectivité internationale, de l'hydrologie des glaciers.

Certain projets avaient pour objets précis d'atteindre des objectifs de recherche à court terme tandis que pour d'autres, le contrôle et la collecte de données a long terme constituaient l'élément fondamental pour la connaissance des systèmes des glaciers. Des installations de recherche bien équipées, semi-permanentes, ont été construites à plusieurs sites de contrôle à long terme et certains d'entre eux ont également servi de points de départ pour des projets de recherche à court terme ou portant sur un aspect précis.

Il y a eu évolution des objectifs de certain âlong terme; il convient surtout de noter le passage de l'étude très intensive de petits bassins a l'application des connaissances acquises à des modèles hydrologiques a l'échelle régionale. On verra probablement, à l'avenir, une plus grande insistance sur des modèles qui intègrent tous les aspects de l'hydrologie de

haute montagne et des modèles qui examinent les rapports entre le climat, les glaciers et l'hydrologie.

IHD OBJECTIVES FOR GLACIER STUDIES

In the mid 1960s, under the auspices of Unesco, the IHD program was conceived. The underlying principle was that for a period of ten years hydrologists around the world should collect standardized hydrological and meteorological data within small, carefully chosen research basins. Basins would be selected to encompass the variety of meteorological and hydrological conditions prevalent in each country. Such a data collection system would allow all relevant processes to be studied and the standard data collection format would allow intercomparison of results.

Glacier basins were considered as a sub-set of hydrological basins and, because of the particular nature of the glacier environment, a special set of required measurements had to be devised. Thus the major elements to be studied included the heat, ice and water balances within the basins as well as the interactions between climate and glacier response on short- and long-term scales.

The following topics for glacier research, all of which are relevant to understanding basin hydrology, were specified for special research efforts:

(a) Comparison of mass and energy transfer processes in snow fields and ice in various locations,
(b) Transformation and melting of snow and ice by thermal and mechanical means,
(c) Dynamics of glacier movement,
(d) Development of instrumentation for measuring volume and properties of snow and ice,
(e) Long-term mass balance of glaciers and ice caps,
(f) Erosion and sedimentation caused by glaciers,
(g) Discharge of snow, ice and water through a transverse section through a glacier,
(h) Circulation of water in the interior of a glacier.

Recommendations were also made that, for intercomparisons on an international scale, three chains of research basins be set up - one to circle the globe at about 45°N, another circum-polar chain in the Arctic and a third North - South transect along the western side of the Americas. These recommendations are laid out more fully in Unesco, (1970).

THE CANADIAN IHD REPRESENTATIVE GLACIER BASIN PROGRAM

The government of Canada (initially through the Geographical Branch and subsequently through the Inland Waters Branch, the Water Resources Branch and the National Hydrology Research Institute (NHRI) responded to the international initiative by creating six representative glacier basins - Sentinel, Place, Woolsey, Peyto, Ram River and Decade - at all of which a full set of hydrological, meteorological and glaciological measurements were to be made. These basins were chosen with a number of criteria in mind: they were to be typical, reasonably small, accessible, not heavily crevassed and preferably with some history of previous observation (Østrem, personal communication). The basins were also to be well defined and have single outlet streams which could be accurately gauged.

In addition, a number of research projects at other glaciers were set up and some of these, namely those at Berendon, Per Ardua, White and Baby Glaciers, were subsequently unofficially incorporated into the representative glacier basin program. These have been described by Løken (1970) and by Stanley (1975). The location, characteristics and a brief listing of major standardized data holdings are found in Tables 1, 2 and 3 and Fig.1. For a more complete review of Canadian glacier hydrology and mass balance studies up to the early 1980s reference is made to Young and Ommanney (1984). To put Canadian studies in their world-wide context, reference is made to Collins (1984) and Young (1982, 1985).

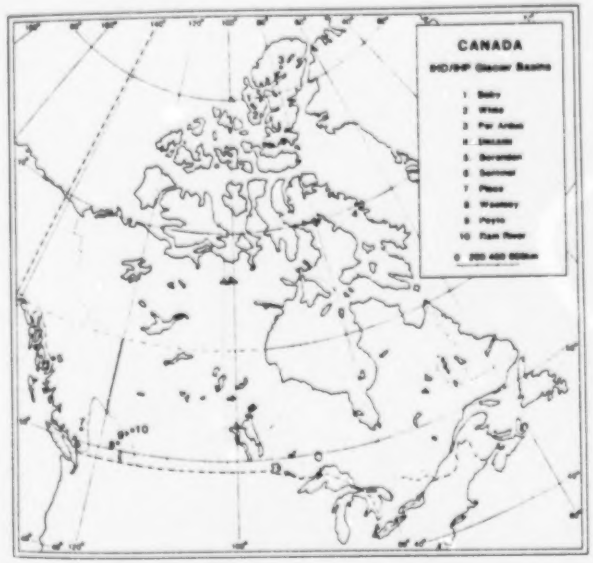

FIG.1. Location of Canadian IHD/IHP Glacier Basins.

It is evident from the tables that there was considerable variability in length (and quality) of the data records. Excellent records of basic heat, mass and water balances were obtained from Sentinel, PLace and Peyto Glaciers; heat and mass balance records from White and Baby Glaciers were very good; the records at Ram River and Woolsey were shorter, but still good; records at Berendon, of heat and mass balance, were good for the two years of record (but were sufficient to accomplish the prime goal of the study which was to estimate the likelihood of glacier advance); the records at Decade and Per Ardua were very short and have proven of minimal usefulness for analysis.

TABLE 1 Location of Canadian glacier representative basins.

Glacier Name	Major Region	Specific Location	Latitude	Longitude
Baby	Axel Heiberg Is	Expedition Area	79 26 N	90 58 W
White	Axel Heiberg Is	Expedition Area	79 27 N	90 40 W
Per Ardua	Ellesmere Is	Tanquary Fiord	81 31 N	76 27 W
Decade	Baffin Island	Inugsuin Fiord	69 38 N	69 49 W
Berendon	Coast Mountains	Steward BC	56 15 N	130 05 W
Sentinel	Coast Mountains	Garibaldi Park	49 54 N	122 59 W
Place	Coast Mountains	Birken BC	50 26 N	122 36 W
Woolsey	Interior Ranges	Columbia Mts	51 07 N	118 03 W
Peyto	Rocky Mountains	Wapta Icefield	51 40 N	116 15 W
Ram River	Rocky Mountains	Front Frange	51 51 N	116 11 W

* Arctic Transect
* N-S Transect in the Americas
* W-E mid latitude transect

TABLE 2 Physical characteristics of glacier representative basins.

Glacier Name	Orient Ac	Orient Ab	Elevation (m) High	Elevation (m) Mean	Elevation (m) Low	Area km sq	Length km
Baby	SW	SW	1175	1000	715	.68	1.60
White	SE	SE	1782	900	53	37.95	15.30
Per Ardua	SW	SW	1705	1150	305	4.26	5.40
Decade	NW	NW	1467	1098	395	8.47	6.10
Berendon	E	E	3210	1350	650	33.40	10.00
Sentinel	N	NW	2100	1800	1525	1.99	2.20
Place	NW	NE	2610	2100	1820	3.96	4.50
Woolsey	NE	NE	2665	2238	1915	3.92	2.90
Peyto	NE	NE	3185	2635	2125	13.40	5.30
Ram River	NE	N	3020	2750	2560	1.80	2.10

In retrospect, the Canadian commitment to the internationally agreed to program was a minimal one. Data were indeed collected at a small number of basins, the most useful results coming from the west-east transect in the southern Cordillera. There was little attempt, however, to promote an integrated approach to data collection and analysis, much less to relate Canadian studies to studies elsewhere. Data summary reports were produced for Sentinel, Place, Peyto and Ram River Glaciers, Mokievsky-Zubok and Stanley (1976a, 1976b), Young and Stanley (1976a, 1976b); reports were not produced for Woolsey and Decade Glaciers. Reports on work accomplished on Axel Heiberg Island are listed in Ommanney (1987). Results of mass balance investigations were, however, reported for all Canadian glaciers through the Permanent Service on the Fluctuation of Glaciers, IASH (1967), IAHS (1973, 1977) and have been summarized by Mokievsky-Zubok et al. (1985).

While basic data collection was thus of variable quality, a perhaps unforseen benefit from the program was that at some glaciers, particularly at

Peyto and to a lesser extent at White, many additional special studies were undertaken on a variety of research topics. These studies greatly benefited from the provision of field laboratory facilities provided by the IHD program - indeed they might never have been conducted had not those facilities been available.

TABLE 3 Basic data collections and major agencies involved.

Glacier Name	Basic data holdings: Mass-balance	Hydrology	Meteorology	Major Agencies Involved
Baby	1959-86		1960-86	McGill, Trent, ETH Zürich
White	1959-86			McGill, Trent, ETH Zürich
Per Ardua	1965-73			Dept. National Defence
Decade	1965-73	1965-68		NHRI
Berendon	1967-69			NHRI
Sentinel	1965-87	1965-87	1965-87	NHRI
Place	1965-87	1965-87	1965-87	NHRI
Woolsey	1971-75			NHRI
Peyto	1966-87	1967-83	1967-83	NHRI, Ottawa, Manchester, Toronto
Ram River	1966-75	1970-74		NHRI

THE CANADIAN IHP GLACIER BASIN STUDIES

In 1975 the IHD program was renamed the IHP. Many of the existing IHD basin studies continued more or less unchanged in many parts of the world. However, there were some important changes in program emphasis. The most significant of these were a realisation that the research findings obtained in the glacier basins had to be integrated into high mountain hydrology as a whole and that glacier/climate interactions should be more specifically emphasised and studied.

In Canada, studies on six of the ten glacier basins were terminated during or at the end of IHD. On the remaining four, Sentinel, Place, Peyto and White, basic data collection has continued with only little modification into the mid 1980s. The program on the west coast was in fact expanded to include mass balance investigations on several other glaciers. In the Rocky Mountain area, studies on Woolsey and Ram River Glaciers were terminated in 1975 so that more detailed studies could be conducted on the more accessible Peyto Glacier and so that studies of comprehensive high mountain hydrology could be undertaken in the vicinity of Peyto. ETH Zürich continued studies on Axel Heiberg Island, in particular on White Glacier and these studies have been more recently supplemented and continued by groups from Trent University.

It is mainly in the period since the end of IHD that many of the detailed studies on glacier hydrologic processes have been undertaken and written up. Considerable understanding of glacier/climate interactions, internal glacier hydrology and discharge from glacier basins has been gained in this time. In addition useful studies on glacier depth, ice movement and glacier mapping by remote sensing and photogrammetric techniques have been completed. The data collected and the understanding of the processes involved have been ad are being incorporated into streamflow simulation models such as the UBC watershed model (Quick & Pipes, 1977).

THE CANADIAN IHD/IHP GLACIER STUDIES IN CONTEXT

It can be argued that for the IHD/IHP in general, and for glacier studies in particular, Canadian hydrological research has been more greatly influenced than have the programs in most other countries. Alpine and Scandinavian countries already had strong glacier programs in existence before IHD and indeed the importance of high-mountain hydrology has been embedded in the national thinking of such countries for a long time. In those regions IHD programs were to a large extent absorbed into already existing national programs. In many less developed nations the IHD programs were never seriously implemented at all and so their effects were negligible. In the mid 1960s and through the 1970s an enormous effort was made by the Federal Government and by many universities to structure their research efforts towards IHD goals, with many good results but sometimes to the detriment of other possible programs.

It is undoubtedly true that a great deal was learned about hydrological processes in a number of small glacier basins. It is also true, however, that the study of total mountain hydrology and regional or large-basin hydrology suffered as a result of so much effort being put into detailed glacier studies. This bias is now somewhat being rectified. Studies to investigate processes in non-glacier covered alpine areas are now being undertaken, and the knowledge of glacier hydrological processes is being incorporated to a greater degree into watershed simulation models.

The whole process of IHD/IHP can now be assessed in a historical perspective. It is apparent that IHD started in a time of economic optimism and expansion. No sooner had the program begun, however, then severe financial restraints were imposed on expenditures. This trend has lasted to the present and seems likely to continue unabated. The failures of the program can largely be attributed to this trend; the more inaccessible and therefore more expensive operations in the Arctic tended to be the first to suffer, and the more expensive of the Cordilleran operations soon followed suit.

Clearly there have been successes and failures in the program. One of the biggest successes was unforeseen at the start of IHD, namely that some of the basins became very successful field laboratories for a variety of experiments and research efforts; this was not only because research facilities existed at glacier sites, but that the wealth of basic data collected proved invaluable in setting the detailed experiments in context.

THE FUTURE

While there have been many basic data reports published and while many papers have been written on a great variety of research topics, there are still many results to be written up from the investigations already undertaken. To a considerable extent there has been an overemphasis on data collection activities without the needed analytical follow-up. Although there have been several studies comparing glacial meteorological and mass balance studies on a world-wide basis, there has yet to be produced a good comparative study of the extensive work carried out on Canadian glacier mass balance, and glacier/climate relations.

In addition there have been no real efforts to evaluate just how "representative" the study basins really are. The very fact that the glaciers chosen had to be of easy access and easy to move around on while neighbouring glaciers are commonly steeper and heavily crevassed begs the question of whether the combination of processes active in the research basins is in fact typical for the region. It can be reasonably argued that the same physical processes are active on all glaciers and thus the results of the studies

undertaken can be applied to all glaciers; however, the precise way in which results are to be transposed to glaciers with substantially different surface topographies is still a largely unresolved question. This is a major prerequisite for the application of the results gained in the small glacier basins to larger basins containing dozens or hundreds of glaciers.

The glaciers studies must be integrated into the general context of high-mountain hydrology; this is a necessary pre-requisite to the integration of IHD/IHP results into forecasting models relating to extensive regions. Considerable activity is taking place in this area of research and development. The World Meteorological Organization, over the past several years, has undertaken intercomparisons of runoff models; this exercise has encouraged the integration of rainfall, snowmelt and glacier ice melt into more general models.

While the results of these studies have as yet been little used by water managers (partly because the results have not been adequately integrated into general hydrology and partly because investigation of mountain hydrology is not perceived as a high priority activity) it is likely that the results will be required in future when it becomes apparent that climate change is having a considerable effect on mountain hydrological regimes. The application of some of the latest General Circulation Models assuming doubling of CO_2 in the next 50 - 100 years indicates major changes in the water balance of the Western Cordillera. It may well be that the baseline data collected at small mountain glaciers over the last two decades prove invaluable as the basis for monitoring these predicted climate changes.

CONCLUSIONS

The IHD/IHP has had a tremendous effect on the conduct of Canadian glacier research since the mid 1960s; possibly a greater effect on Canadian research than on the research conducted in any other country.

The whole program would likely not even have been able to start had the economic climate of the 1960s not been so propitious; it is slightly ironic therefore that the failures of the program have been largely attributable to increasingly difficult economic times.

We will never again be in a position similar to that in the 1960s and it is therefore unlikely that we shall see a program oriented towards identical research conducted in a number of small basins.

The final irony is that prior to the IHD a number of studies were being conducted looking at regional hydrology problems; during IHD attention was focused on detailed processes in very restricted areas; the challenge is now seen to be the incorporation of these detailed results into a larger scale picture so that once again we can address problems in regional hydrology.

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Waterford River Basin urban hydrology study - review of the approach

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ABSTRACT The urban areas in the province with increasing population and economic development are experiencing a wide variety of water management problems including flooding, erosion and sedimentation, deteriorated water quality, lowering of groundwater table, loss of recreational facilities and aesthetics. The data on impacts of urbanization on surface water and groundwater in Newfoundland is almost nonexistent, which makes it difficult to develop effective management strategies including urban drainage design criteria. The five year (1980-1985) federal-provincial Waterford River Basin Urban Hydrology Study was designed to examine the processes leading to changes in the hydrologic regime, to apply available models and to recommend solutions to specific water management problems. The study called for a comprehensive approach which included hydrometric surveys, hydrological modelling, groundwater studies, biological surveys, water quality assessment, investigation of flooding, and land use analyses. This paper summarizes the results of various components of the study and outlines the problem and difficulties which were experienced in the hydrometeorological networks design and processing of data, analysis and interpretation of data including the application of hydrologic models, and other aspects of the study. Hydrologic peculiarities of the region such as high rainfall-runoff ratios (80-90%) are highlighted and emphasize the need for developing adequate database in the province. Urbanization did not proceed as anticipated because of economic difficulties and, consequently temporal changes in flow regime in urbanizing watersheds could not be monitored and verified with model results. Despite some unexpected problems, the study has provided valuable results which will help in developing water resource management policies and strategies in urban areas. The approach in general has proved useful and may successfully be adopted in such studies in the future.

RÉSUMÉ Suite à l'accroissement de leur population et au développement économique, les zones urbaines de la province font face à un variété de problèmes de gestion d'eau incluant les inondations, l'érosion et la sédimentation, la détérioration de la qualité de l'eau, l'abaissement de la nappe, la perte de zones récréatives et l'esthétique. Il n'existe que très peu de données sur l'impact de l'urbanisation sur les eaux de surface et souterraines à Terre-Neuve, ce qui rend difficile le développement des stratégies d'aménagement efficaces, incluant des critères de conception de drainage urbain. L'étude fédérale-provinciale d'hydrologie urbaine du bassin de la rivière Waterford, d'une durée de cinq ans (1980-1985), a été conçue

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